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Importance of Seedyear, Seedbed, and Overstory for Establishment of Natural Loblolly and Shortleaf Pine Regeneration in Southern Arkansas

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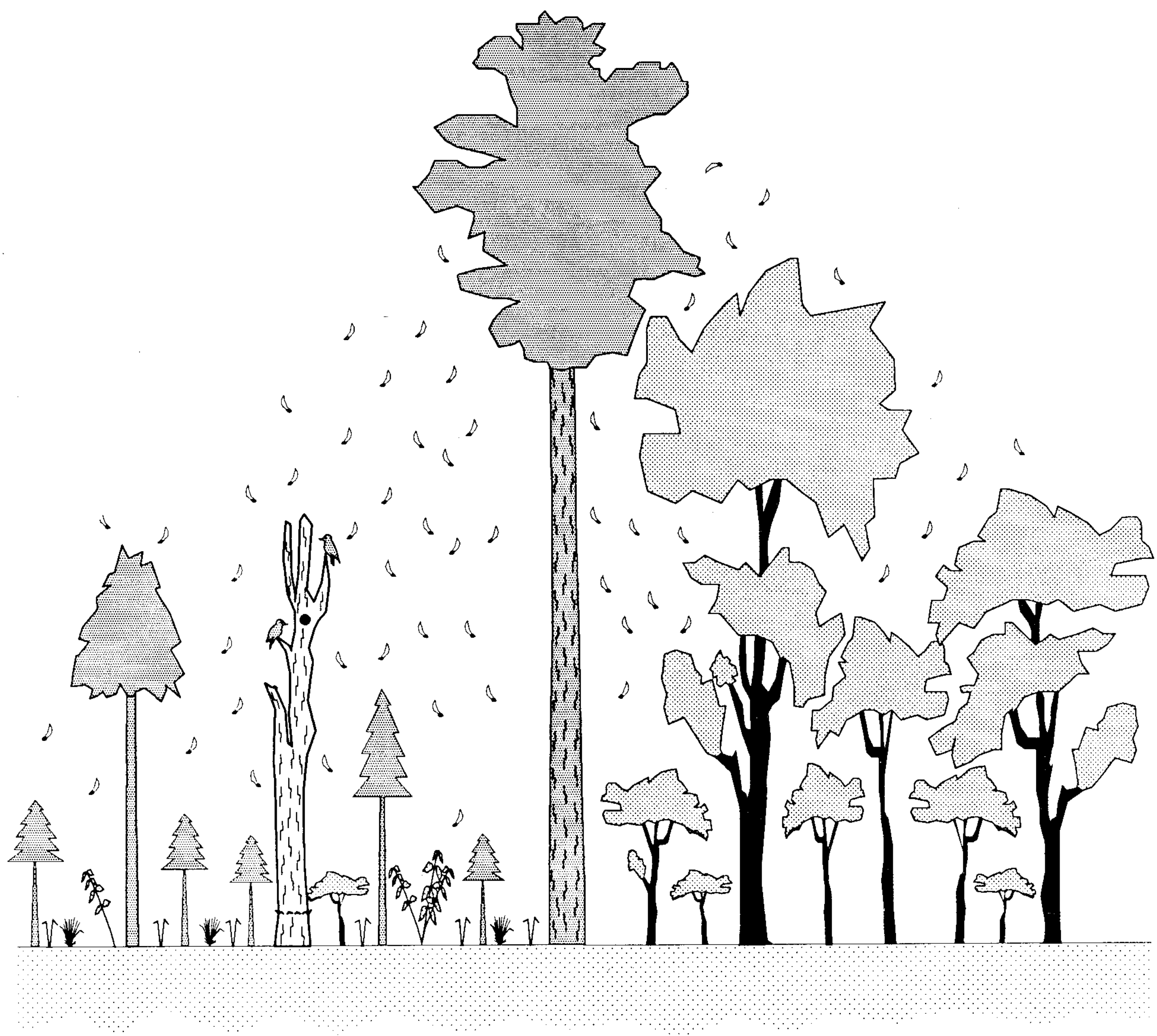

SUMMARY

A study was installed in two uneven-aged, pine-hardwood stands in southern Arkansas to determine the effects of different seedyears and seedbed conditions on first-year density and quadrat stocking of natural loblolly and shortleaf pine (*Pinus taeda* L. and *P. echinata* Mill.) regeneration. When the study was installed, merchantable basal area averaged about 120 square feet per acre, with 50 percent of that in pines and 50 percent in hardwoods. Pine seedling counts relative to seedcatch in 5 succeeding years were compared on untreated check plots and on plots where hardwoods were controlled by stem injection of herbicides. Injected plots contained both undisturbed seedbeds (pine-hardwood litter) and disturbed seedbeds (mineral soil exposed).

During the 5-year study, seedcrops ranged from a complete failure to over 1 million potentially viable seeds per acre. Pine seedling densities were well correlated with the seedcrops. Pine seedling density and quadrat stocking were significantly less and generally unacceptable on uninjected plots compared to density and stocking on injected plots. Plots with exposed mineral soil had a smaller seeds-per-seedling ratio than inject-only plots, but gains in pine seedling density as a result of raking were not as great as those achieved by injection alone.

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INTRODUCTION

Although planting pine seedlings for regeneration purposes is an accepted practice throughout the South, most of the loblolly and shortleaf pines (*Pinus taeda* L. and *P. echinata* Mill.) that are being harvested today came from natural regeneration. For continued success with natural stand management, four requirements must be met when regenerating stands of loblolly and shortleaf pine: (1) a suitable seedbed, (2) an adequate supply of seeds, (3) sufficient soil moisture for seed germination and seedling establishment, and (4) freedom from excessive competition after establishment.

A number of research studies have been conducted in the vicinity of Arkansas (Gemmer 1941, Grano 1949, Grano 1971, Liming 1945, Phares and Liming 1961) and elsewhere in the Southeastern United States (Pomeroy 1949, Pomeroy and Trousdell 1948, Trousdell 1950, 1954, 1963, Trousdell and Langdon 1967) to determine the relationship of these four requirements to the establishment of natural loblolly and shortleaf pine regeneration. However, many of the earlier investigations incorporated intensive site disturbance in combination with logging activity, were conducted in a single seedyear, or used direct seeding in place of natural seedfall. In view of these irregularities, up-to-date information is needed to supplement or confirm results obtained from historical investigations.

The purpose of this study was to determine the density and quadrat stocking of natural loblolly and shortleaf pine seedlings relative to the abundance of seed produced from uneven-aged pine stands, with and without hardwood control. The study included both disturbed and undisturbed seedbeds, which were prepared over a period of 5 years to account for the variability of natural seedcrops. Logging was excluded from the study because favorable seedbed conditions created by cultural treatments can be masked by seedbeds created by logging disturbance (Trousdell 1963). For this investigation, the pine-hardwood stands were specified by relative basal area, with basal area for merchantable-size pines ranging from 50 to 80 percent of total basal area (Cain 1989).

METHODS

Study Areas

The study was conducted in two test areas on the Crossett Experimental Forest in southern Arkansas. Soil in the study areas is Bude (Glossaquic Fragiudalf) and Providence (Typic Fragiudalf) silt loam, and site index is 85 to 90 feet at 50 years for loblolly pine (USDA 1979). Annual precipitation averages 55 inches; extremes are wet winters and dry autumns.

Test Area A.—At the time of study installation, this uneven-aged stand consisted of mature loblolly and shortleaf pines that averaged 19 inches in diameter at breast height (d.b.h.); the 10 largest pines averaged 76 years old. Merchantable pine basal area averaged 69 square feet per acre, and understory and midstory hardwood basal area averaged 60 square feet per acre. The understory was relatively open, with no pine regeneration and very little herbaceous vegetation because of shading from the midstory and overstory. The last improvement cut was in 1963.

Test Area B.—Compared to test area A, this uneven-aged stand contained more pines in the smaller size classes, averaging 11 inches in d.b.h., but average age of the 10 largest pines was 63 years. For pines less than 4 inches in d.b.h., density averaged about 14 trees per acre. Basal area averaged 63 square feet per acre for the pine component and 55 square feet per acre for understory and midstory hardwoods. Herbaceous vegetation was sparse. No harvesting had taken place since 1967.

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The only known disturbance on the two test areas before study installation was prescribed burning in February 1980. The fires were cool and did not consume the litter down to mineral soil.

Treatments

The effects of annual seedfall, hardwood midstory and overstory, and seedbed preparation on the establishment of loblolly and shortleaf pine regeneration were studied. Seedcrops were monitored during each of five consecutive seedyears, beginning with the winter of 1985–86.

The absence of pine regeneration in these stands might have been the result of overstory and midstory hardwoods shading the forest floor. To investigate this possibility, hardwoods greater than 1 inch in groundline diameter were stem injected on designated plots in the summer before each scheduled seedyear. The herbicides Tordon® 101R (undiluted) and Roundup® (50-percent solution in water) were used for deadening the hardwoods. Tordon was the principal herbicide, but Roundup was used to control sweetgum (*Liquidambar styraciflua* L.) and ash (*Fraxinus* L. spp.), which are resistant to Tordon.

Undisturbed and disturbed seedbeds were tested in the following manner. On one-half of each injected plot, the pine-hardwood litter was left undisturbed (inject-only treatment). On the other half, mineral soil was exposed by use of a tractor-mounted raking device and by hand-raking (inject/rake treatment). The litter removal techniques were meant to simulate mineral soil exposure that could be achieved operationally by prescribed burning or logging disturbance, but soil displacement was minimal. Raking was always completed just before October 1 of scheduled seedyears. There was no mineral soil exposure nor hardwood injection on check plots.

Experimental Design

Each test area contained 4.4 acres, with 18 plots measuring 66 by 66 feet (0.1-acre plots). Year of seeding and undisturbed checks were randomly assigned to the 18 plots within each test area. During any one seedyear, seedbed treatments were replicated on three 0.1-acre plots per test area. The same three check plots per test area were used during each of the five seedyear assessments.

Using a split-plot design, disturbed and undisturbed seedbeds were assigned at random to 0.05-acre subplots within each 0.1-acre gross plot. To achieve that design, plots were split in a north-south direction. On the interior 0.025 acre of each 0.05-acre subplot, a series of eight systematically established circular quadrats of 0.3 milacre each were used to inventory seedling catch. After the fifth year, two circular quadrats of 0.00125 acre were systematically established on each interior 0.025 acre for assessing height class distribution of pine regeneration and percent ground cover.

Measurements

Once plots were established, overstory pines were inventoried by 1-inch d.b.h. classes on all 0.1-acre plots. Basal area was computed on a plot-by-plot basis.

A 1⁄20th-milacre seed collection trap was placed at the center of each 0.05-acre subplot, 2 feet above ground. Seedtraps were installed after raking and before October 1 of each seedyear on those plots that had been injected the preceding summer, and on the three check plots in each test area. Seed counts were made weekly from October through February. Pine seeds collected in traps were cut open, and those containing fully developed gametophyte tissue were judged as potentially viable (Bonner 1974). That process was repeated for each seedyear, with 24 seedtraps monitored per year.

At the end of a single growing season following the designated seedyear, pine seedling counts were taken within the eight circular quadrats per interior 0.025 acre, and percent quadrat stocking of seedlings was based on these counts. The six check plots were similarly inventoried but on an annual basis. Only first-year pine seedlings were counted after each seedyear.

When pine seedling counts were made for a particular seedyear on the 0.05-acre subplots, overstory pine d.b.h. measurements were taken on those same subplots for computation of basal area. These data were to be used as independent variables in covariance analysis, but basal area proved to be nonsignificant and was subsequently abandoned as a covariate.

Depth of litter was measured at the time of seedling inventories on each sample quadrat in undisturbed subplots where hardwoods had been injected the previous year, as well as on untreated check plots. Litter depths were taken to the nearest 0.1 inch.

After the fifth-year inventory, pine seedling counts were taken by 1-foot height classes on all plots that had been monitored during the 5-year study. At the same time, ocular assessments of percent vegetative ground cover (hardwood, pine overstory, pine seedlings, and herbaceous vegetation) were estimated to the nearest 10 percent.

Data Analysis

Analyses of variance were used after the fifth year to evaluate pine seedling density and percent quadrat stocking relative to seedyear and seedbed treatments. Data from check plots were compared to that from the inject-only and inject/rake plots (check vs. inject/rake comparison), and data from inject-only plots were compared to inject/rake plots according to a split-plot design (inject vs. rake comparison).

In all analyses, data from each of the two test areas were analyzed separately only when test areas were significantly different. Duncan's New Multiple Range Test was used to isolate differences between seedyear means. Percent quadrat stocking and percent ground cover were analyzed following arcsine $\sqrt{\text{proportion}}$ transformation. Linear regressions were generated to illustrate the relationship of pine seedling density to the number of potentially viable seeds. All analyses were carried out at the 0.05 level of significance.

RESULTS AND DISCUSSION

Pine Seed Production

During the 5-year study, annual production of potentially viable seeds across seedbed treatments ranged from about 3,000 per acre (poor seedcrop) to over 1 million per acre (bumper seedcrop) (table 1). There was a statistically significant interaction between seedyears and seedbed treatments for the check versus inject/rake comparison only. That interaction is attributed mainly to the change in magnitude of seeds collected on check plots, which averaged higher in 1990 relative to numbers on inject/rake plots (table 1).

The mean number of viable seeds collected on injected plots averaged 26 percent more than the mean number of seeds per acre collected on check plots (table 1). Those differences may, however, be more apparent than real. Seed-producing pines were the

Table 1.—*Pine seed production and first-year seedling density on three seedbed treatments during five seedyears*

Measurement variable and seedyear	Seedbed		Seedyear mean*	Seedbed		Seedyear mean*
	Check	Inject/rake		Inject	Rake	
Seed production	*Potentially viable seeds / acre (thousands)*					
1986	1.7	3.3	2.5a	3.3	3.3	3.3a
1987	993.3	1390.0	1191.7c	1343.3	1436.7	1390.0c
1988	50.0	58.3	54.2a	50.0	66.7	58.3a
1989	321.7	296.7	309.2b	336.7	256.7	296.7b
1990	43.3	23.3	33.3a	16.7	30.0	23.3a
Seedbed mean	282.0	354.3		350.0	358.7	
Mean square error	1.4910E10			1.4684E10		
P>F† (Seedbed)	(0.03)			(0.78)		
P>F† (Seedyear)			(0.00)			(0.00)
P>F† (Seedbed by seedyear)			(0.00)			(0.55)
Seedling density	*Stems / acre*					
1986	174	174	174a	70	278	174a
1987	14931	277049	145990b	191250	362847	277049b
1988	729	3993	2361a	1042	6944	3993a
1989	1597	13577	7587a	6320	20834	13577a
1990	798	1181	990a	1111	1250	1181a
Seedbed mean	3646	59195		39959	78431	
Mean square error	9.1121E08			1.8905E09		
P>F† (Seedbed)	(0.00)			(0.00)		
P>F† (Seedyear)			(0.00)			(0.00)
P>F† (Seedbed by seedyear)			(0.00)			(0.00)

*Within each measurement variable, columnar means followed by the same letter are not significantly different at the 0.05 level.

†The probability of obtaining a larger F-ratio under the null hypothesis.

dominant trees on these plots and overtopped midstory hardwoods by 50 feet or more. Hardwood trees on check plots retained their leaves well into the peak period of pine seedfall, and those leaves served as barriers to keep pine seeds from falling directly into the seedtraps. In contrast, on injected plots, hardwood leaves had either withered or dropped off before pine seedfall began each year and did not hinder seed collection.

The bumper seedyear in 1987 produced over a million potentially viable seeds per acre and was significantly better than any other seedyear (table 1). The better-than-average seedyear of 1989 produced significantly more seeds than the average seedyear of 1988 or the below-average seedyears of 1986 and 1990. Those differences held true for all plot locations. The proportion of overstory shortleaf pines to all pines in these mixed stands averaged 30 percent or less; consequently, shortleaf pines made only a small contribution to overall seed production.

Pine seedfall tended to reach maximum intensity in November (fig. 1). The exceptions to that rule were the two extreme seed production years. During the bumper seedyear of 1987, seedfall remained high through January. Similarly, during the poor seedyear of 1986, no seeds were found in traps until December. For the seedyears 1988, 1989, and 1990, more than 90 percent of potentially viable seeds had fallen by the end of December. During the bumper seedyear of 1987, however, 90 percent seedfall was not achieved until early February. These data suggest that the benefits of natural pine seedfall would be maximized in most years if seedbed preparation was completed before early autumn.

Pine Seedling Density

Pine seedcrops were an accurate indicator of first-year seedling density. The bumper seedyear of 1987 produced the most pine seedlings, and the poor seedyear of 1986 produced the fewest (table 1). Because of extreme variation within seedyears, the bumper seedcrop was the only one to produce statistically significant differences in mean density between seedyears. These analyses also were done using seeds per acre as a covariate, but the covariate was subsequently deleted because there was no improvement in the results.

There were statistically significant interactions between seedbed treatments and seedyears for the check versus inject/rake comparison and the inject versus rake comparison. These interactions are attributed to a change in the magnitude of response (table 1). The mean density on injected plots exceeded the density on check plots every year except 1986. Seedling density was also similar on inject-only and on rake plots in 1990 but was distinctly different in all other years.

Seedbed treatments resulted in a 1,500 percent increase in the number of first-year seedlings compared

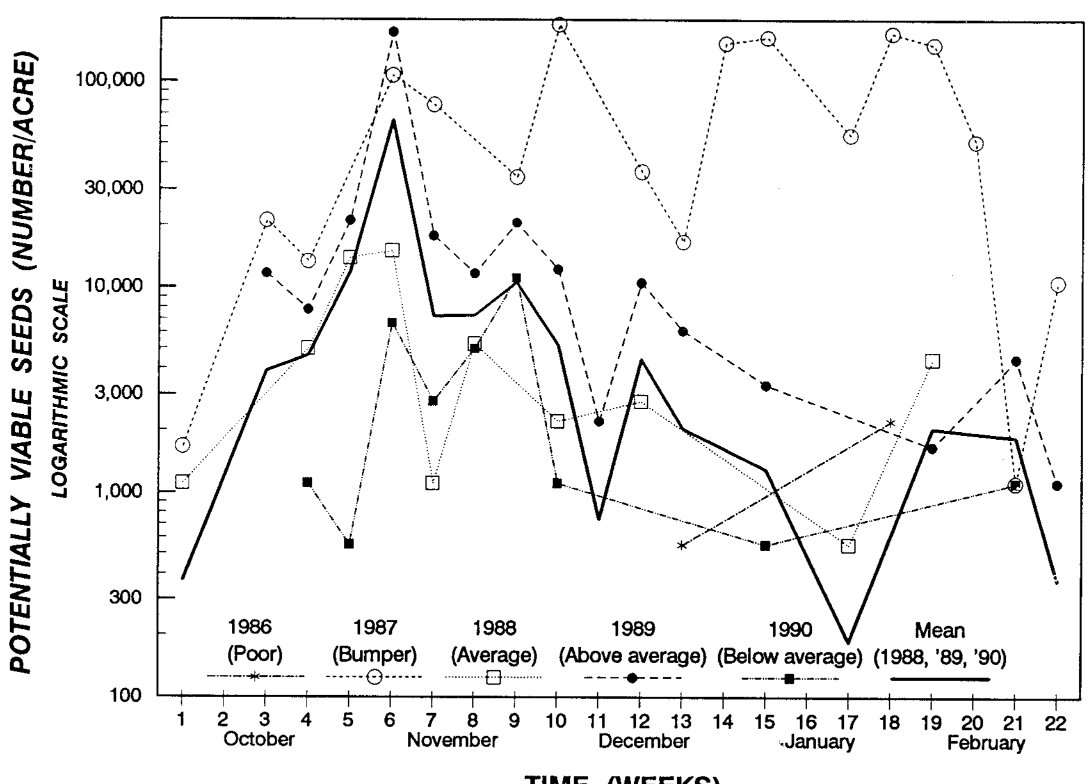

Figure 1. — *Trends in weekly pine seed production by seedyear.*

to check plots (table 1). Exposure of mineral soil in combination with hardwood injection produced 96 percent more seedlings than injection alone.

It is often speculated that more intensive site preparation is needed in below-average seedyears in order to produce an adequate stand of natural pine seedlings. Nevertheless, results of this study indicate that hardwood injection alone was sufficient to produce an adequate density of pine seedlings in all but the poorest seedyear (1986). In regulated uneven-aged loblolly-shortleaf pine stands, a rule of thumb is that density of natural pine regeneration should be 200 stems per acre, with at least 50-percent milacre stocking. In 1986, even raking in combination with hardwood injection resulted in a seedling catch (278 trees per acre) that would be borderline, at best, for uneven-aged management (Cain and others 1987) and totally inadequate for even-aged management (Grano 1967). Consequently, the added expense of more intensive site preparation would not be justified when relying on natural pine regeneration in a poor seedyear. On the other hand, a ground cover of herbaceous vegetation at the time of scheduled pine regeneration would almost certainly require more intensive site preparation than hardwood injection alone, even during good seedyears (Cain 1991).

The linear relationships of the common logarithm of first-year pine density to the common logarithm of the number of potentially viable seeds exhibited high coefficients of determination (r^2) (fig. 2). The best correlations were achieved where the hardwood component had been deadened. On check plots, an average of 114 potentially viable seeds were required to produce a single seedling. That compares to 22 seeds per seedling on inject-only plots and 12 seeds per seedling on inject/rake plots.

There was a significant interaction between seedyear and seedbed treatments for the inject versus

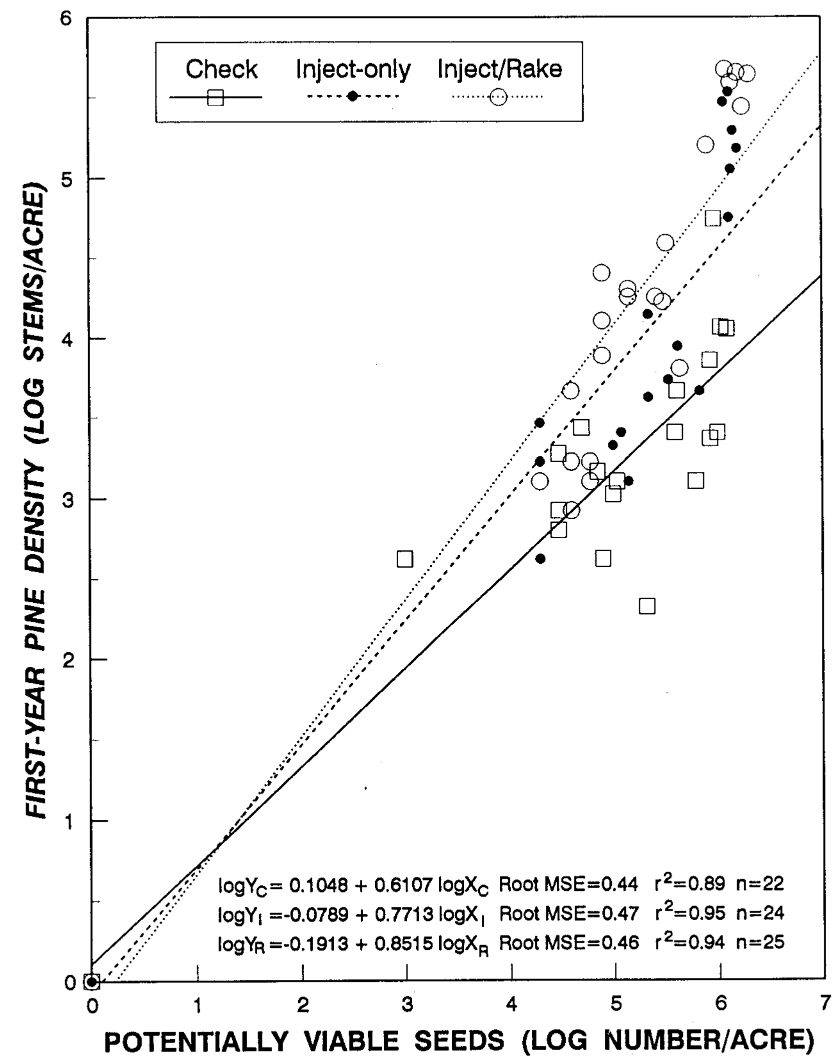

Figure 2. — *Relationship of the common logarithm of first-year pine seedling density to the common logarithm of the number of potentially viable seeds.*

rake comparison of seeds per seedling. More seeds were required to produce a seedling on inject-only plots compared to rake plots in 1986, -87, -88, and -89; however, the opposite was true in 1990. For main effects, 1989 was the only seedyear of the five to require significantly more seeds per seedling. One explanation is that, in 1989, over 26 inches of precipitation were recorded on the Experimental Forest from May through August, compared to an average of about 16 inches for the same 4 months in the other 4 years. Excess moisture may have increased the activity of damping-off fungi that, in turn, killed more seedlings in 1989 and resulted in a higher seeds-per-seedling ratio by the end of that growing season.

Quadrat Stocking of Pine Seedlings

Quadrat stocking was one variable for which there were statistically significant differences between test areas; consequently, data were analyzed separately by test area (table 2). Poorer stocking of pine seedlings (stems less than 1 inch in d.b.h.) in test area B compared to test area A was attributed to more prolific herbaceous competition and a greater density of merchantable-size pines (fig. 3).

For the check versus inject/rake comparison of quadrat stocking, there was a significant interaction between seedyears and seedbeds in test area B, but not in test area A (table 2). On test area B, there was a change in the direction of response; that is, check plots had higher quadrat stocking than inject/rake plots following the 1986 seedcrop but less stocking in subsequent years. That anomaly was not apparent in test area A, where quadrat stocking was consistently higher on inject/rake plots compared to check plots in all 5 years (table 2). For main effects, inject/rake plots averaged 24-percent better quadrat stocking than check plots in both test areas.

Test area B also had significant seedyear by seedbed interactions for the inject versus rake com-

Table 2.—*Quadrat stocking of first-year pine seedlings on three seedbed treatments during five seedyears*

Test area and seedyear	Seedbed: Check	Seedbed: Inject/rake	Seedyear mean*	Seedbed: Inject	Seedbed: Rake	Seedyear mean*
Test area A	Percent†					
1986	2	8	5a	0	17	8a
1987	77	100	88d	100	100	100c
1988	23	63	43bc	42	83	62b
1989	37	79	58c	71	87	79bc
1990	25	33	29b	37	29	33a
Seedbed mean	33	57		50	63	
Mean square error	186.12			128.84		
P>F‡ (Seedbed)	(0.00)			(0.01)		
P>F‡ (Seedyear)			(0.00)			(0.00)
P>F‡ (Seedbed by seedyear)			(0.27)			(0.10)
Test area B	Percent†					
1986	8	2	5ab	4	0	2a
1987	64	100	82d	100	100	100d
1988	6	17	12b	0	34	17b
1989	8	80	44c	63	96	80c
1990	0	4	2a	0	8	4a
Seed mean	17	41		33	48	
Mean square error	69.05			118.18		
P>F‡ (Seedbed)	(0.00)			(0.01)		
P>F‡ (Seedyear)			(0.00)			(0.00)
P>F‡ (Seedbed by seedyear)			(0.00)			(0.03)

*Within test areas, columnar means followed by the same letter are not significantly different at the 0.05 level.

†Based on the presence of at least one pine seedling per quadrat.

‡The probability of obtaining a larger F-ratio under the null hypothesis.

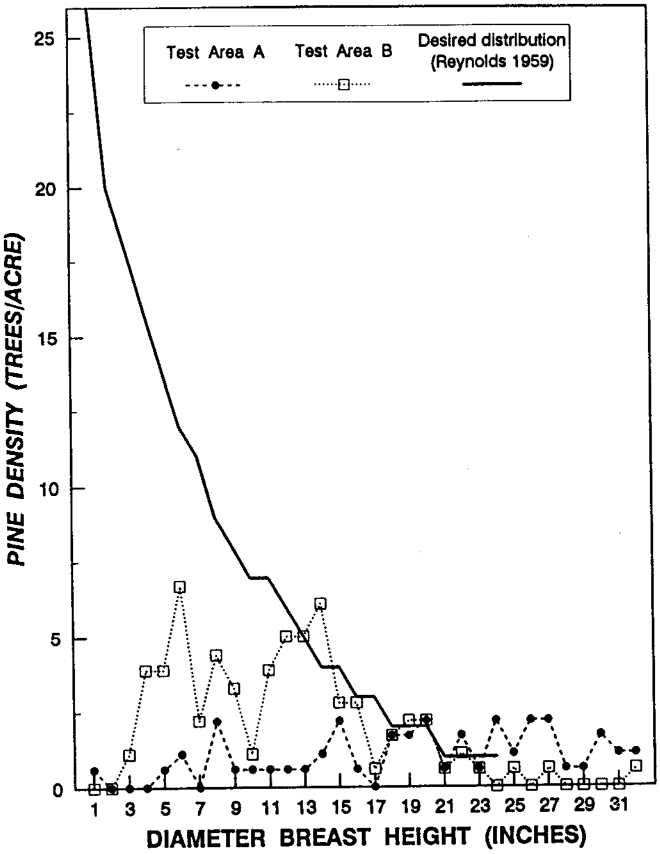

Figure 3. —*Initial pine diameter distribution by test area compared to the desirable distribution for a regulated uneven-aged stand of loblolly-shortleaf pines.*

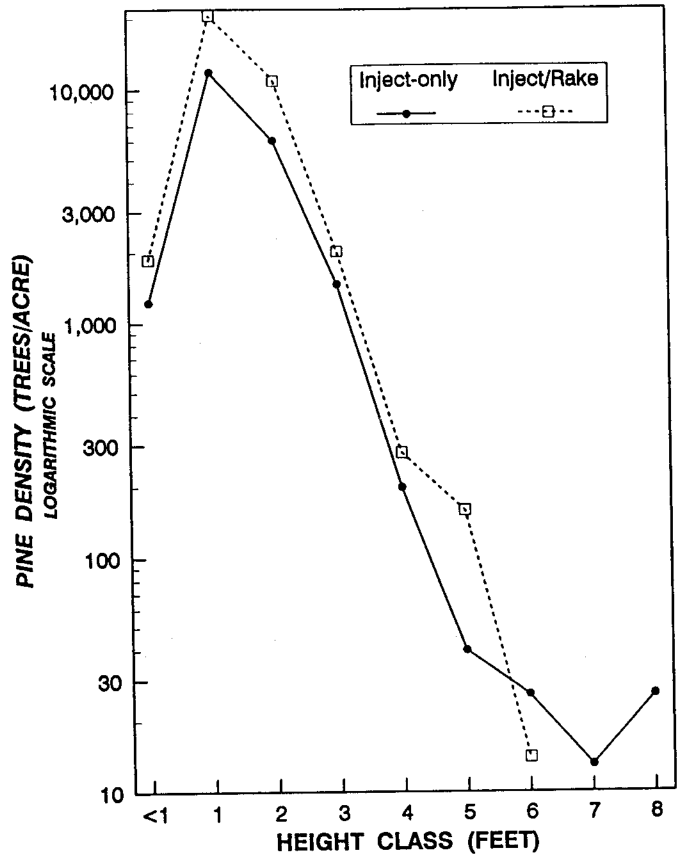

Figure 4. —*Height class distribution of pine seedlings by seedbed treatment after 5 years.*

parison, but no significant interaction occurred in test area A (table 2). Significant interaction was attributed to a lack of stocking on the inject-only plots in 1988 and 1990.

Raking to expose mineral soil produced significantly better quadrat stocking of first-year pine seedlings than hardwood injection alone in both test areas (table 2). Even so, raking was not effective in producing adequate stocking of first-year pine seedlings during the poor (1986) or the below-average (1990) seedyears. Those two seedyears produced significantly less and totally inadequate quadrat stocking, regardless of test area. Understocking also occurred on Test Area B following the average seedcrop of 1988.

Pine Seedling Size and Overstory Basal Area

Density of pines was plotted relative to their height across all five seedyears to illustrate the distribution of seedlings by size class on inject-only and inject/rake plots (fig. 4). Exposure of mineral soil made no substantial contribution to the subsequent growth of pine seedlings. Another point of interest is that naturally regenerated pine seedlings can be expected to grow no taller than 8 feet during a 5-year period if basal area of merchantable-size pines averages about 64 square feet per acre on silt loam soils, even when overtopping hardwoods are intensively controlled.

Overstory pine basal area ranged from 60 square feet per acre on inject/rake plots to 67 square feet per acre on inject-only plots, with no statistically significant differences between seedbed treatments for the check versus inject/rake comparison or the inject versus rake comparison. Such basal area levels are well within those recommended—55 to 75 square feet per acre—for the establishment of loblolly and shortleaf pine regeneration from natural seedfall in uneven-aged stands (Reynolds and others 1984).

Most overstory pines on Test Area A were larger than 15 inches in d.b.h., whereas the majority of pines on test area B ranged from 3 to 16 inches in d.b.h. (fig. 3). Height to live crown averaged 68 feet (high shade) for overstory sample pines on test area A, compared with 40 feet (low shade) for sample pines on test area B. Even though overall basal area was similar, a greater density of midstory and overstory pines as well as low shade is less desirable for pine seedling growth than high shade from fewer overstory pines. These factors may have contributed to significantly lower quadrat stocking of pine seedlings on test area B compared to test area A (table 2).

After 5 years, hardwood trees that were 1 inch in d.b.h. and larger averaged 65 square feet per acre on check plots in test area A and 72 square feet per acre on check plots in test area B. At that time, hardwoods made up 49 percent and 51 percent of total basal area on check plots in test area A and B, respectively.

When the study was installed, oaks (*Quercus* spp. L.) comprised 69 percent of the 60 square feet of hardwood basal area per acre across all plots on Test Area A and 50 percent of the 55 square feet per acre on Test Area B. The largest oaks were *Q. alba* L., *Q. falcata* Michx., *Q. nigra* L., and *Q. stellata* Wangenh. Predominant midstory and understory hardwoods included *Acer rubrum* L., *Cornus florida* L., *Liquidambar styraciflua* L., *Nyssa sylvatica* Marsh., and *Ulmus alata* Michx. Sweetgums and blackgums accounted for 15 percent of total hardwood basal area on both test areas A and B. At the time of study establishment, the crowns of these hardwoods formed a closed canopy that resulted in complete shading of the forest floor. Hardwoods exhibited the classic reversed-J diameter distribution common in uneven-aged stand structure, and hardwood d.b.h.'s ranged from 1 to 20 inches.

Natural pine regeneration is most likely to occur if hardwood basal area is substantially less than 20 percent of total basal area in regulated uneven-aged loblolly-shortleaf stands (Cain 1989). Although unproven, preliminary results of light attenuation measurements in uneven-aged pine-hardwood stands suggest that when pine and hardwood basal area are equal, the pines shade the forest floor only half as much as the hardwoods.[1] Given these facts, natural pine regeneration might be expected to fail when a well-distributed mixture of pine and hardwood basal area exceeds 60 and 8 square feet per acre, respectively.

Litter Depth and Vegetative Ground Cover

The forest floor litter on check and inject-only plots consisted of hardwood leaves, pine needles, and other detritus that had fallen from trees. Mean litter depth after the first year of treatment averaged 1.3 inches; it was the same after the last year of treatment. Obviously, annual input of litter was in equilibrium with decomposition. Grano (1949) studied the effects of litter on the establishment of loblolly and shortleaf pine from natural seedfall in the Crossett Experimental Forest. He found that the depth of pine-hardwood litter averaged 1.3 inches on milacres that contained over 7,000 first-year pine seedlings per acre. He concluded that a good seedling stand was not dependent on disturbance of that litter on these sites. Results of the present investigation tend to confirm that conclusion.

In addition to basal area from overstory pines and hardwoods, another measure of competition effects on pine seedling establishment is percent ground cover by various vegetative components. After 5 years, hardwoods on check plots produced 90 percent cover, and that degree of cover contributes to an understanding of why there was a lack of pine seedlings on those plots. Because of multistoried layers, overstory pines provided 24-percent cover on check plots, and herbaceous vegetation added another 18 percent. Herbaceous vegetation included forbs, grasses, semi-woody plants, and vines.

In contrast to check plots, the principal cover component on the inject-only and inject/rake plots was herbaceous vegetation, which averaged more than 50 percent when all years were combined. Within 3 years after injection, reinvading hardwoods produced about 5 percent ground cover, while herbaceous vegetation contributed over 75 percent ground cover (fig. 5). By the fourth year however, these hardwoods began to

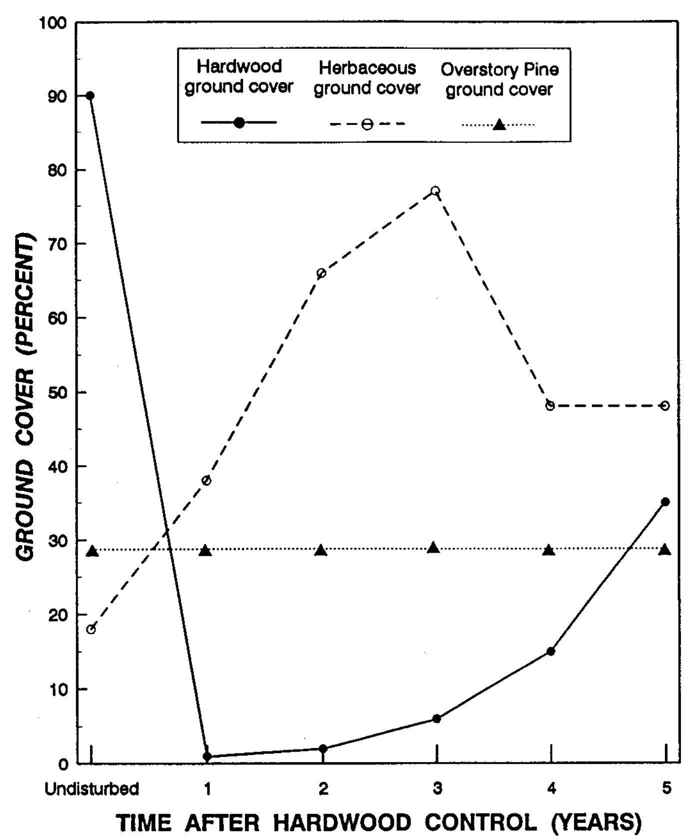

Figure 5.—*Five-year trends in vegetative ground cover following hardwood control by inject-only and inject/rake treatments.*

[1]Shelton, M.G. 1991. Unpublished data. Field notes on file with USDA Forest Service, Southern Forest Experiment Station, Monticello, AR 71655.

exert more shading on the forest floor, which resulted in a decrease of the herbaceous cover. In the fifth year, cover from reinvading hardwoods generally exceeded that of the pine overstory.

After 5 years, ground cover from pine seedlings averaged more than 40 percent on plots that were injected in 1986, the poorest seedyear. These seedlings obviously came from the bumper seedcrop of 1987. Therefore, an opportunity exists to naturally seed areas with pine even though a seedcrop failure may occur during the year of seedbed treatment—unless, of course, seedtrees are eliminated from the site. During this 5-year study, there were never two successive seedcrop failures.

MANAGEMENT IMPLICATIONS AND CONCLUSIONS

Of all the variables examined in this 5-year study, the one that stands out as the main inhibitor of natural pine regeneration was shading by midstory and overstory hardwoods that averaged from 55 to 60 square feet of basal area per acre when the study began. That was true despite the fact that two out of five seedyears produced better-than-average seedcrops.

The poor seedyear of 1986 produced an average of 2,500 potentially viable seeds per acre, a number totally inadequate to establish an operational stand of pine seedlings. Seedcrops in all other seedyears averaged 30,000 or more potentially viable seeds per acre and resulted in satisfactory density of pine seedlings on plots where hardwoods were controlled. However, percent stocking of pine seedlings was not always adequate, even during average seedyears.

When seedyears were average or better, hardwood injection alone was sufficient to produce an adequate density of pine seedlings. Simply eliminating the hardwood midstory and overstory resulted in a fivefold reduction in the seeds-per-seedling ratio that was required on untreated check plots. The seeds-per-seedling ratio on inject-only plots was cut in half by exposing mineral soil (raking), but that enhancement procedure was apparently less effective than hardwood injection alone. Only in the poor seedyear of 1986 did injection alone result in inadequate density of pine seedlings for uneven-aged management when compared to injection plus mineral soil exposure. Even so, raking to expose mineral soil did not produce adequate quadrat stocking of pine seedlings following the 1986 seedcrop. Therefore, the use of intensive site preparation treatments cannot be recommended for seedbed amelioration during a poor seedyear. If overtopping hardwoods are controlled just before scheduled cycle cuts in uneven-aged stands of loblolly and shortleaf pines, then logging activity during those cycle cuts should expose enough mineral soil to facilitate natural pine regeneration on silt loam soil during most seedyears.

It must be emphasized that herbaceous vegetation on the forest floor was sparse when the inject-only and inject/rake treatments were applied each year. Consequently, intensive competition control of herbaceous ground cover was not needed in this study. When the forest floor is covered by an abundance of forbs, grasses, vines, and semiwoody plants, then intensive control measures will be required to ensure an adequate stand of pine seedlings even during good seedyears (Cain 1991). Seedbed treatments to enhance natural pine regeneration should be completed by early autumn.

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First-year density and quadrat stocking of naturally established loblolly and shortleaf pine regeneration were monitored for five consecutive seedyears on disturbed and undisturbed seedbeds. Compared to untreated checks, additional gains in pine seedling density as a result of exposing mineral soil were not as great as initial gains achieved by control of overtopping hardwoods.

Keywords: Basal area, forest floor, hardwood control, herbaceous vegetation, litter depth, *Pinus echinata* Mill., *P. taeda* L., seeds per seedling, uneven-aged management.

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